



## External post-tensioning of cfrp tendons using integrated sleeve-wedge anchorage

Schmidt, Jacob Wittrup; Bennitz, Anders ; Goltermann, Per ; Lund Ravn, Dorthe

*Published in:*

Proceedings of the 6th International Conference on FRP Composites in Civil Engineering

*Publication date:*

2012

[Link back to DTU Orbit](#)

*Citation (APA):*

Schmidt, J. W., Bennitz, A., Goltermann, P., & Lund Ravn, D. (2012). External post-tensioning of cfrp tendons using integrated sleeve-wedge anchorage. In *Proceedings of the 6th International Conference on FRP Composites in Civil Engineering : CICE 2012*

---

### General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

# EXTERNAL POST-TENSIONING OF CFRP TENDONS USING INTEGRATED SLEEVE-WEDGE ANCHORAGE

## **Jacob Wittrup Schmidt**

Title PhD, Post Doc  
University or Affiliation Danish Technical University, DTU and COWI A/S  
Address Brovej, Building 118, DK-2800 Kgs. Lyngby  
*email address* jws@byg.dtu.dk

## **Anders Bennitz**

Title PhD, Consulting Engineer  
University or Affiliation Vectura AB  
Address Västra Varvsgatan 11, Luleå, Sweden  
*email address* anders.bennitz@vectura.se

## **Per Goltermann**

Title PhD, Professor  
University or Affiliation Danish Technical University, DTU  
Address Brovej, Building 118, DK-2800 Kgs. Lyngby  
*email address* pg@byg.dtu.dk

## **Dorthe Lund Ravn**

Title MSc, Senior specialist, Consulting engineer  
University or Affiliation COWI A/S  
Address Parallelvej 2, Kgs. Lyngby  
*email address* dlr@cowi.dk

## **Abstract**

Strengthening of structures using external post-tension CFRP systems have proven to be an efficient method as such system increases the structural capacity and reduces cracks and deflection. Sufficient anchorage is of significant importance since the anchorage provides the connection between the post-tensioning system and the remaining structure. A special designed integrated sleeve-wedge anchorage has therefore been designed to improve the reliability of the mounting procedure, reduce the possible modes of failure and thus provide desired anchorage. The present research shows that adequate anchorage was obtained using the novel anchorage and that its behaviour is stable and predicatble when short term static load is applied. Desired strengthening was also observed in external post-tensioning on reinforced concrete T-beams. The requirements and definitions on a stable anchorage of CFRP tendons however still need to be investigated further.

**Keywords:** Post-tensioning, CFRP, anchorage, failure modes, external, T-beam

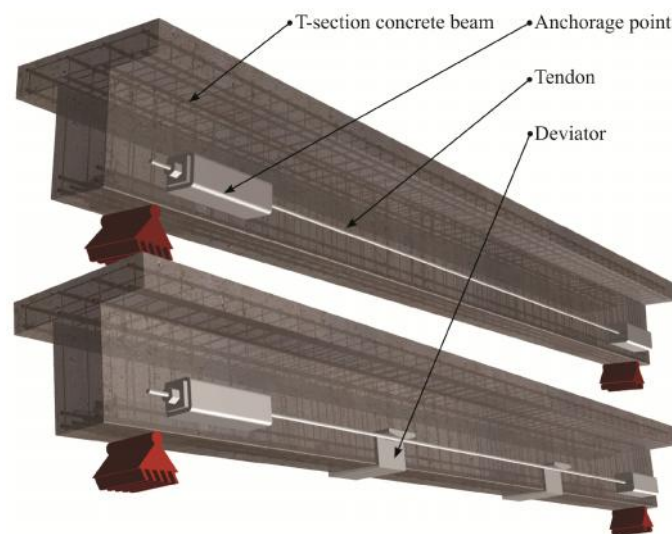
## **1. Introduction**

Strengthening of structures using externally bonded CFRP materials has gained increased attention during the past decades for a number of reasons, e.g., heavier and more intensive traffic, deterioration of materials along with decreasing structural capacity and upgrading or change in national standards, etc. Such systems have significant corrosive resistance compared to steel and solve some of the main demands- and challenges given in many national societies too. With the strengthening of a structure the CO<sub>2</sub> emissions might be reduced significantly compared to the alternative of replacing the structure. In addition the systems are cost efficient and traffic and other live loads can often continue during installation.

Strengthening using bonded CFRP (Carbon Fibre Reinforced Polymers) materials is one of the externally applied systems, which can be used for this purpose efficiently. Strengthening can be carried out using non post-tensioned and post-tensioned CFRP applications. The non post-tensioned systems, CFRP plates, CFRP sheets and NSMR (Near Surface Mounted Reinforcement) bars, are usually bonded to the structure (normally concrete or steel) using epoxy [1], [2], [3]. A post-tensioned system is often seen to be identical to non-post-tensioned CFRP system, but has an initial strain applied when mounted, [4], [5], [6]. An initial applied strain acting normal to the cross section is beneficial since it increases both shear and bending capacity of the strengthened structure (provided sufficient concrete reserves). In addition the amount of cracks and deflection is reduced. An alternative to the use of epoxy is to use unbonded systems.

### 1.1 External unbonded post-tensioning

External post-tension systems using unbonded CFRP tendons have been documented as an efficient strengthening system, [7], [8], [9]. Such systems are mounted on the structure using two anchorage points and, when desired, a deviator is introduced to keep distance between the tendon and centroid of the strengthened section. An example of external post-tensioning is seen in Figure 1. Advantages of such CFRP systems are the low weight, resulting in fast mounting, and the accessibility, which eases inspection of the system. Easy accessibility however also makes the external system susceptible to fire, sabotage and vibrations. The anchorage of the CFRP tendon have received much attention as it is often the critical area of the system, since the load transfer between post-tensioning system and remaining structure occurs at these locations, [10]. A CFRP fracture in the anchorage region could result in total loss of post-tensioning, thus strengthening is lost.



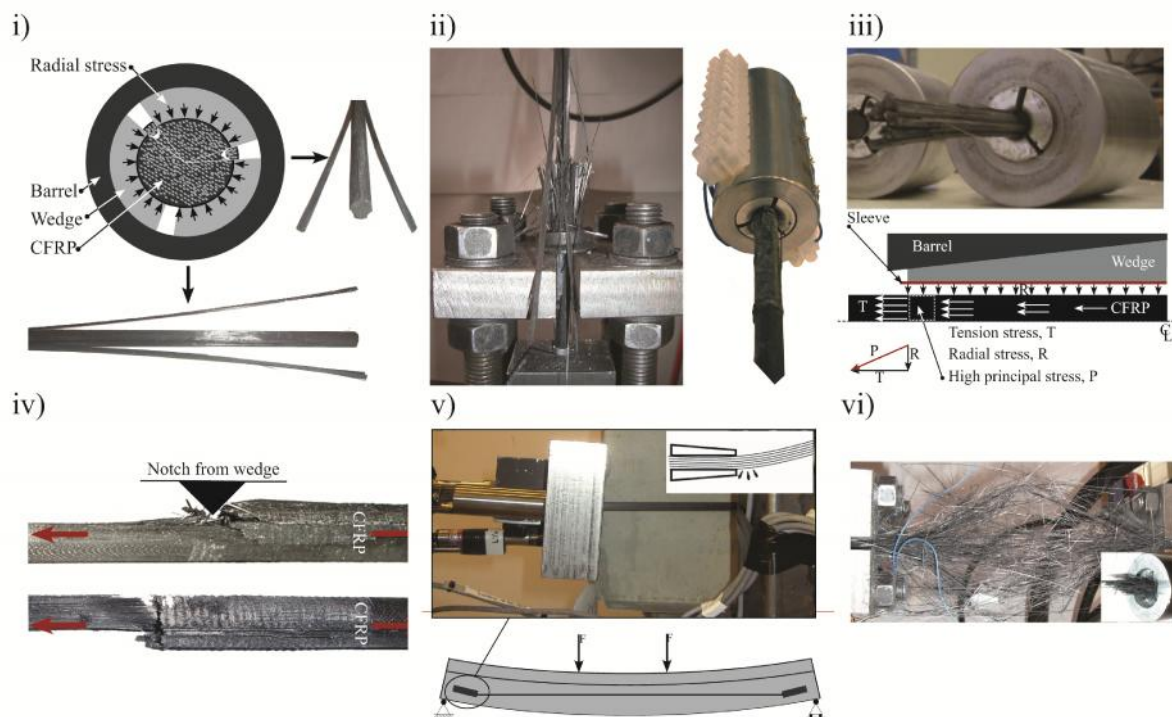
**Figure 1. Example of a deviated and non deviated T-section beam**

Design of an anchorage which is reliable, robust and competitive to existing steel pre-stressing has therefore gained considerable attention by researchers. Bonded [11], [12], [13] - and mechanical anchorage [14], [15] is commonly used but stresses seems to be easier to control using mechanical anchorage. Consequently the mechanical anchorage length is in general significantly shorter. Fast mounting and flexible tendon length are other advantages when using mechanical anchorage.

### 1.2 Mechanical anchorage

Although it is disadvantageous, fracture of the CFRP often occurs at the anchorage since high stresses from the applied system are transferred from the tendon to the anchorage further to

the remaining structures in this area. As a consequence stress intensities are often experienced, resulting in premature failure of the tendon. Susceptibility to stress intensities is especially seen when using CFRP tendons, where fracture is sudden (due to the brittle properties), and several failure modes can cause premature failure. Some of these failure modes are, Figure 2: i) Crushing of the rod: Direct contact between the wedges and CFRP causes crushing of the fibres into the gaps of the wedge, ii) Slippage: Occurs either as a soft- or power slip in the wedge/CFRP interface, iii) Frontal overload: A combination between high tension stress in the tendon and stress perpendicular to the fibres, result in a frontal overload due to a high principal stress, iv) Cutting of fibres: Local edges or imperfections in the wedge/CFRP interface result in cutting of the outer fibres thus in premature failure, v) Bending of fibres: When the anchorage is applied to the structure bending in combination with tension could occur, and vi) Desired fracture: Characterized to be a successful fracture.



**Figure 2. Failure modes when performing mechanical anchorage of a CFRP tendon: i) Crushing of the rod, ii) Slippage, iii) Frontal overload, iv) Cutting of fibres, v) Bending of fibres, and vi) Desired fracture.**

It is seen from tests [16] that power slip and desired failure seems to reach the ultimate capacity of the CFRP tendon. I.e. it is not possible to use the type of failure mode alone as a criterion for what a stable anchorage is. Information concerning the acceptance criteria, reliability and robustness is still a shortcoming and should be discussed further.

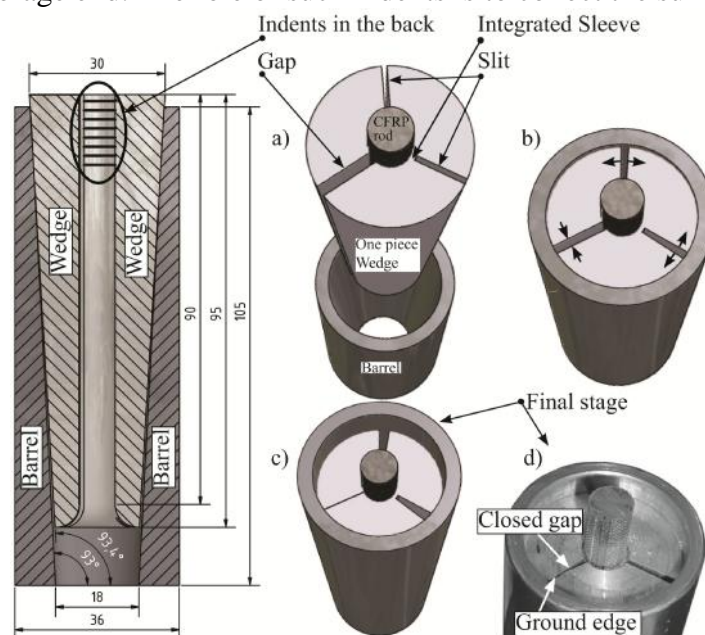
## 2. Aim and scope

The presented research aims to examine if an anchorage can be made stabile at the ultimate stress level of the CFRP tendon to be post-tensioned. In addition the possibility of fast anchorage in combination with controlling and prediction of failure modes was investigated. A new anchorage design was developed to study if desired anchorage was one of the main contributors towards a stabile external post-tensioning system.

## 3. Integrated sleeve-wedge anchorage

In order to perform stabile anchorage and reduce failure modes an integrated sleeve-wedge anchorage was developed. The novel anchorage system was developed in Denmark and Sweden [e.g., Technical University of Denmark (DTU), COWI Denmark, Luleå University of

Technology (LTU)]. It consists of a one piece wedge (length: 95 mm, largest outer diameter: 21 mm) and a barrel (length: 105 mm, outer diameter: 30 mm), designed with an angle difference (0.1 degree) between the conical inner surface of the barrel and outer wedge surface, Figure 3. The conical wedge has three cuts down the longitudinal axis which shapes the integrated sleeve i.e. a gap which is a cut through the wedges shell and the slits which are stopped 1mm short of the inside hollow. This configuration results in longitudinal and circumferential gripping, which encloses the CFRP tendon progressively during installation and tensioning of the CFRP tendon, Figure 3, [17]. During installation, the gap is opened to allow insertion of the CFRP tendon, Figure 2a. During this process, the slits are partially closed. When the wedge and enclosed rod are installed into the barrel, the slits open and the gap closes Figure 2b and 2c. The complete circumferential gripping of the CFRP rod results in a confinement pressure so that the CFRP rod cannot escape through the gap that closes in the final installation stage, Figure 2c and 2d. Additionally, the gap opening can be varied to control the pressure onto the rod. Also shown in Figure 3 are indents in the wedge hollow at the unloaded anchorage end. The role of such indents is to collect the surface particles of the



**Figure 3. Integrated sleeve-wedge anchorage geometry and installation: (a) installation of integrated sleeve wedge over CFRP rod; (b) presetting of integrated sleeve wedge; (c) and (d) preset integrated sleeve wedge.**

CFRP rod that have been sheared off from abrasive wear when the rod is highly tensioned. The collected particles result in volumetric expansion which in turn decreases slippage of the CFRP rod. Desired anchorage (Figure 2 vi) and power slip (Figure 2 ii) failure modes was obtained using this design, reaching an ultimate tension capacity of approximately 140 kN. The experimental values was ranging from 118% - 124% of the mean ultimate capacity of the rod (provided by the manufacturer), [16] and the novel design seemed to prevent the other failure modes.

### 3.1 Anchorage material properties

Mechanical properties of the anchorage (wedge + barrel) and 8 mm CFRP tendon is shown in Table 1. The barrel is made from mild steel and the integrated sleeve-wedge is made from aluminum. Mild steel and aluminum exhibit elastic and plastic behavior whereas the encased CFRP materials attribute elastic - brittle behavior. In addition the CFRP tendon has orthotropic properties, which indicates that it consists of different properties in the longitudinal and transverse directions of the fibers. The CFRP tendon is made of a volume

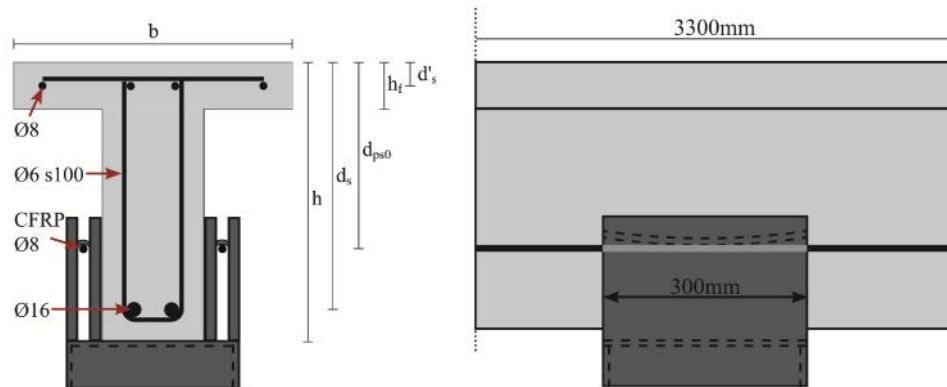
carbon fraction of 70% in a vinylester-epoxy-resin matrix resulting in an elastic modulus of 158 GPa.

**Table 1. CFRP tendon- and integrated sleeve-wedge anchorage material properties.**

	UNIT	CFRP	BARREL	WEDGE
Material	[ - ]	Carbon	Steel	Aluminium (EN-AW-6262-T9)
Resin	[MPa]	Epoxy		
Longitudinal ultimate/yield stress	[MPa]	2800	464/443	70
Longitudinal modulus of elasticity	[GPa]	156	210	70
Major Poisson's ratio	[ - ]	0.27	0.3	0.3
Major Poisson's ratio	[ - ]	0.02	0.3	0.3

#### 4. Full scale testing

Several theoretical evaluations and small scale tests (tension testing of anchorages and CFRP tendons) were performed on the integrated sleeve-wedge anchorage to predict the performance, [17]. However implementation of the anchorage in full scale testing was vital for the understanding and indication if the anchorage system could be used on real life structures. The effect of external unbounded post-tensioning using the novel anchorage was investigated throughout the load scheme for RC (Reinforced Concrete) T-beams, where it was installed in each end of the CFRP tendon, [18]. Geometry of the beams is shown in Figure 4. Dimensions and properties of the T-section were:  $b = 300$  mm,  $b_w = 1000$  mm,  $h = 305$ ,  $h_f = 55$  mm,  $d_s = 265$  mm,  $d'_s = 30$  mm,  $f_c = 28$  MPa - 40 MPa (compressive, cube strength),  $f_t = 2,5$  MPa - 3,78 MPa (tensile, split test). Yield strength, ultimate strength and modulus of elasticity of the deformed steel were 510 MPa, 600 MPa and 187 GPa. Length of the T-beams was 3300 mm with a 3000 mm distance between the supports. Post-tensioning was conducted using both deviated and non-deviated beams. The deviator geometry is illustrated in Figure 4. External post-tensioning was applied to the T-section beam using different stress magnitudes in the tendon, Table 2. The applied stress was a percentage of the ultimate tendon capacity: Applied design force  $F_{ps.design}$  [kN] is the force applied to the cross section by the two external tendons whereas  $F_{ps.design}$  [%] is the post-tensioning percentage compared to the ultimate strength of one external post-tensioning system (Often characterized as the tendon ultimate capacity = Approx. 140 kN)



**Figure 4. T-section and deviator geometry.**

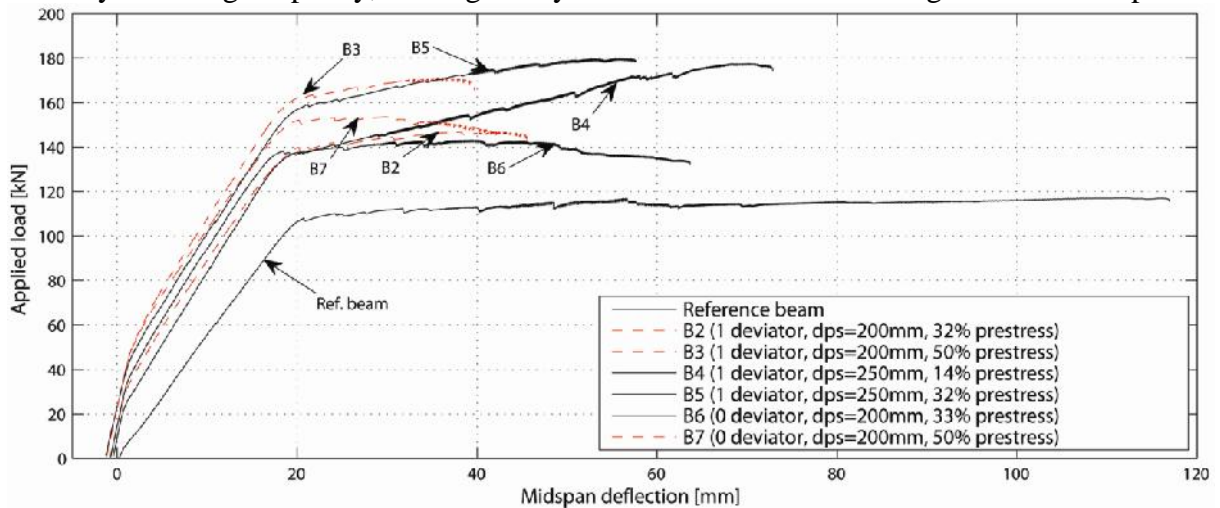


**Table 2. Applied post-tensioning and distance from the concrete top surface to the CFRP tendon.**

BEAM	$d_{ps0}$ [mm]	$F_{ps,design}$ [kN]	$F_{ps,design}$ [%]	Deviated
Ref.	-	-	-	-
B2	200	90	32	Yes
B3	200	140	50	Yes
B4	250	40	14	Yes
B5	250	90	32	Yes
B6	200	90	32	No
B7	200	140	50	No

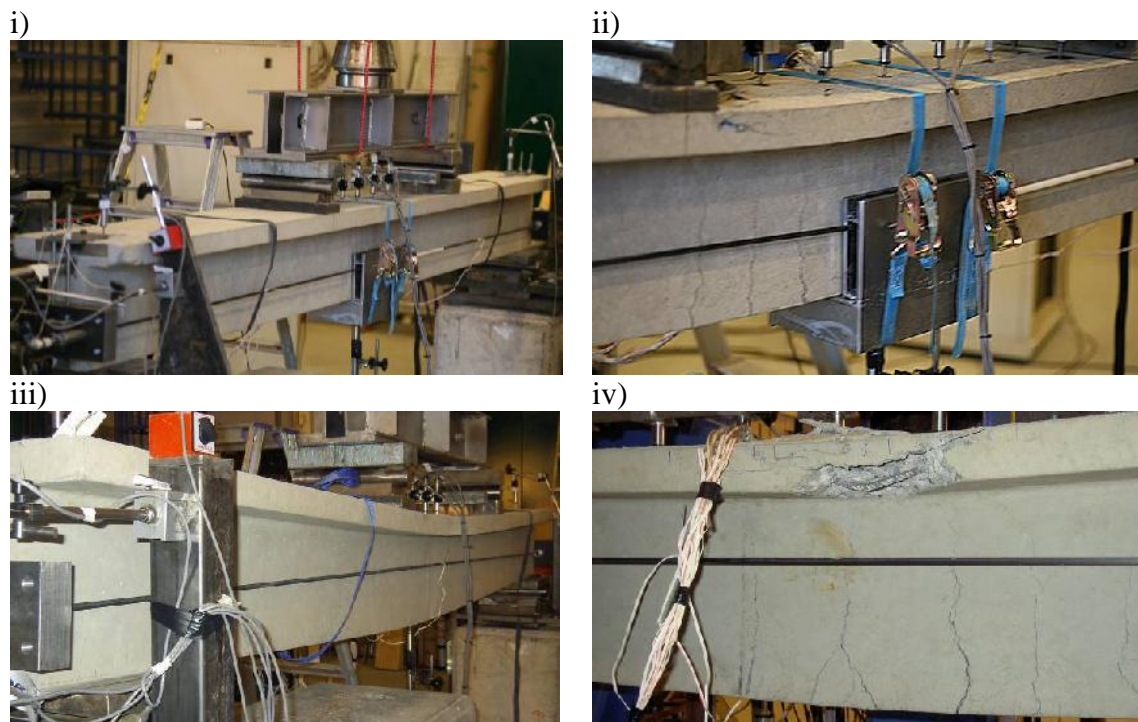
#### 4.1 Results and discussion

The mid span deflection of the post-tensioned beams versus the applied load are displayed in Figure 5 and compared with the un-strengthened reference beam. The post-tensioned beams have a higher failure load and a stiffer behaviour than the reference beam, while the ductility has decreased. A significant difference in behaviour can also be seen within the strengthened beams. Comparison between beams B2 and B6 and beams B3 and B7 with an initial tendon depth,  $d_{ps0}$ , of 200 mm give an insight into the effects of adding a deviator at midspan to the post-tensioned system. A deviator cause a positive inclination of the load carrying capacity in the yielding regime whereas the curve is stable or negative inclined when no deviator is applied. Increasing  $d_{ps0}$  from 200 mm to 250 mm results in a significant increase in capacity. Beams B2 and B6 have the initial post-tension of 32% and 33% respectively and beams B3 and B7 an initial post-tension of 50%. Increased post-tensioning seems to result in increased strengthening effect too. In general deviators provided large increase in capacity but less ductility compared to the non-deviated beams. B4 with 14% post-tensioning both provided ductility and a high capacity, although the yield load is the lowest among the tested setups.

**Figure 5. Example figure caption (centred).**

An example of the test setup and final result is shown in Figure 6 for: i) the deviated beam setup, ii) obtained fracture and cracking at midspan of the deviated beam, iii) non-deviated beam setup, iv) fracture and cracking at midspan of the non-deviated beam. Measurements of

the tendon's movement into the anchorage in relation to the anchorage plate showed a maximum of 0.3 mm movement for the entire series.



**Figure 6.** Test examples of: i) deviated beam setup, ii) obtained fracture and cracking at midspan of the deviated beam, iii) non-deviated beam setup, iv) fracture and cracking at midspan of the non-deviated beam.

## 5. Conclusion

Desired post-tensioning was performed using the integrated sleeve wedge anchorage. It was experienced, through anchorage tension tests, that several failure modes could cause premature failure. Designing a novel anchorage to prevent some of the failure modes was shown to be a good approach thus resulting in stable anchorage in the static load regime. The successful tension tests assured confidence in the further use for full scale post-tensioning of RC T-beams. Deviators ensured a constant distance between the CFRP tendon and the T-section centre of gravity thus providing larger capacity but less ductility compared to the non-deviated beams. It was however seen that desired- and reliable anchorage behaviour plays an important role when post-tensioning is performed. Insufficient anchorage can cause reduction of strengthening effect, uneven stress in the tendons and premature failure, which are uncontrollable effects. It seems important to perform anchoring which can handle the high and sustained tendon force throughout the structures life. A shortcoming is however still the definition of desired fracture in external unbonded post-tensioning systems. Guidelines on FRP anchorage testing lack information and discussions on whether the capacity of the external FRP post-tensioning system relates to the anchorage- or the entire system capacity (anchorage + tendon). It is therefore often seen that acceptance criterions from anchored steel tendons are used when designing externally unbonded CFRP post-tensioning systems.

## 6. Acknowledgment

The writers would like to express their appreciation for the financial support given by COWI A/S and Forsknings og Innovationsstyrelsen.

## 7. References

- [1] TÅLJSTEN, B." Strengthening of Beams by Plate Bonding." *J. Mater. Civil Eng.*, Vol



- 9, No 4, 1997, pp. 206-212.
- [2] TRIANTAFILLOU, T. C., ANTONOPOLOS, C. P. "Design of concrete flexural members strengthened in shear with FRP" *J. Compos. Constr.*, Vol 4, No 4, 2000, pp.198-205.
  - [3] SMITH, S.T. "Modeling Debonding Failure in FRP Flexurally Strengthened RC Members Using a Local Deformation Model" *J. of Comp. for Constr.*, Vol. 11, No. 2, 2007, pp. 184-191
  - [4] STÖCKLIN, I.; MEIER, U. "Strengthening of concrete structures with pre-stressed gradually anchored CFRP strips." *Proc., Fiber-Reinforced Polymer Reinforcement for Concrete Structures*, Cambridge, UK, 2001, pp.291-296.
  - [5] TRIANTAFILLOU, T.C., DESKOVIC, N. "Innovative prestressing with FRP sheets. Mechanics of short-term behaviour" *J. of Eng. Mech.*, Vol 117, 1991, pp.1652-1672.
  - [6] NORDIN, H., TÂLJSTEN, B. 2006. "Concrete beams strengthened with prestressed near surface mounted CFRP" *J of Comp. for Constr.*, Vol 10, No 1, 2006, pp. 60-68.
  - [7] NG, C. K., (2003) "Tendon Stress and Flexural Strength of Externally Prestressed Beams," *ACI Structural Journal*, Vol. 100, No. 5., 2003, pp. 644-653.
  - [8] NAAMAN, A. E., ALKHAIRI, F. M. "Stress at Ultimate in Unbonded Post-Tensioning Tendons: Part 1 - Proposed Methodology," *ACI Structural Journal*, Vol 88, No. 6, 1991, pp. 683-692.
  - [9] HARAJLI, M. H. "On the Stress in Unbonded Tendons at Ultimate: Critical Assessment and Proposed Changes," *ACI Structural Journal*, V. 103, No. 6, 2006, pp. 803-812.
  - [10] REDA TAHA, M. M., SHRIVE, N. G. "New Concrete Anchors for Carbon Fiber-Reinforced Polymer Post-Tensioning Tendons - Part 2: Development/Experimental Investigation." *ACI Struct. J.*, Vol. 100, No. 1, 2003, pp. 96-104.
  - [11] BUDELMANN, H., KEPP, B., ROSTASY, F. S. "Fatigue Behaviour of Bond-Anchored Unidirectional Glass-FRP's" *Proceeding of the material engineering congress – serviceability and durability of construction materials*. Denver, Colorado, 1990. pp. 1142-1151.
  - [12] ROSTASY, F. S. "New approach in the already published recommendations for anchorage assembly". *Proceeding of the 9<sup>th</sup> congress of Federation Internationale de la precontrainte*, 1982. p. 95-98
  - [13] PATRIK, K., MEIER, U. "CFRP Cables for large structures" *Proceeding in advanced Composite materials in Civil Engineering Structures - ASCE*, Specialty Conference. Las Vegas 1991. p. 233-244.
  - [14] AL-MAYAH, A., SOUDKI, K. A., PLUMTREE, A. "Experimental and analytical investigation of a stainless steel anchorage for CFRP prestressing tendons" *PCI Journal*, Vol. 46, 2001, pp. 88-100.
  - [15] SAYED-AHMED, E.Y. "Single- and multi-strand steel anchorage systems for CFRP tendons/stays". *Proceeding in 4<sup>th</sup> Structural epeciality conference of the Canadian society for civil engineering*. Canada Montréal, Québec, 2002. pp.1381-1390.
  - [16] SCHMIDT, J. W., SMITH, S. T., TÂLJSTEN, B., BENNITZ, A., GOLTERMANN, P., and PEDERSEN, H., "Numerical Simulation and Experimental Validation of an Integrated Sleeve-Wedge Anchorage for CFRP Rods" *J. of Comp. Constr.* V. 15, No. 3, 2011, pp. 284-292.
  - [17] SCHMIDT, J. W., BENNITZ, A., TÂLJSTEN, B., and PEDERSEN, H., "Development of Mechanical Anchor for CFRP Tendons Using Integrated Sleeve," *Journal of Composites for Construction*, V. 14, No. 4, 2010, pp. 397-405.
  - [18] BENNITZ, A., Externally Unbonded Post-Tensioned CFRP Tendons – A System Solution, Doctoral thesis, Luleå University of Technology, Luleå Sweden, 2011, p. 68.